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European Patent Office  
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(11) Publication number:

**0 090 432**  
**A2**

**EUROPEAN PATENT APPLICATION**

(21) Application number: 83103247.9

(51) Int. Cl.<sup>3</sup>: **C 08 K 3/08, C 08 K 7/06,**  
**H 05 K 9/00, G 12 B 17/02**

(22) Date of filing: 31.03.83

(30) Priority: 31.03.82 JP 52610/82  
05.04.82 JP 56175/82

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(43) Date of publication of application: 05.10.83  
Bulletin 83/40

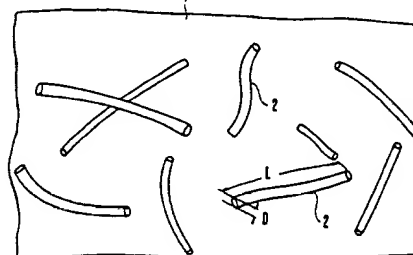
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(84) Designated Contracting States: **DE FR GB IT**

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(54) **Electro-magnetic wave absorbing material.**

(57) An electro-magnetic wave absorbing member comprises a mixture of short fibers (2) of metal or alloy having a high electro-conductivity, a length of 0.1 mm to 50 mm and a length to diameter ratio larger than 10, ferrite and a high molecular weight synthetic resin. In a modification a sheet of this material is used as a low input impedance layer (13) and laminated with an electro-conductive sheet (12) and an impedance conversion layer (14). The member according to this invention can increase electrical loss contributing to the absorption of electro-magnetic waves, can stably control the absorption and can be used in many applications.



# Electro-magnetic Wave Absorbing Material

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This invention relates to electro-magnetic wave absorbing material.

Such material is used for preventing ghosts of iron towers, ships, etc. in radar systems, and for  
10 preventing generation of unwanted electric wave and dispersion thereof.

As disclosed in Japanese Laid Open Patent Specification No. 36987/1980, a prior art electro-magnetic wave absorbing material was constituted by a mixture of  
15 ferrite, carbon black and a high molecular weight synthetic resin. Such material absorbs electro-magnetic wave energy by the magnetic loss caused by ferrite and electric loss caused by carbon black. Accordingly such electro-magnetic wave absorbing material is coated or  
20 deposited on the surface of a metal or electro-conductive sheet to a specific thickness so as to form an electro-magnetic wave absorber.

The capability of absorbing electric wave of such an absorber, however, differs depending upon the frequency and  
25 intensity of the electric wave to be absorbed so that it has been desired to provide improved electro-magnetic wave absorbing material or member having a high absorbing

efficiency.

In order to increase the loss of the electro-magnetic wave imparted by the absorbing material described above, it is necessary to increase the quantities of incorporation of ferrite and carbon. However, even when the quantity of ferrite is increased there is a limit for the magnetic loss, while carbon black can increase electric loss, its function becomes unstable due to variations in electric conductivity and particle size.

As is well known in the art, the electro-magnetic wave absorption capability of the electric wave absorbing member described above has the maximum absorption efficiency when the input impedance  $Z$  as measured from the surface of a layer of the electro-magnetic wave absorption material is unity, where

$$Z = \sqrt{\frac{\mu_2}{\epsilon_2}} \tanh \left( j \frac{2\pi}{\lambda} \sqrt{\epsilon_2 \mu_2} d \right)$$

where  $\epsilon_2$  represents a complex dielectric constant of the absorption layer,  $\mu_2$  a complex permeability,  $\lambda$  the wavelength and  $d$  the thickness of the absorption layer.

However, the frequency bandwidth in which a condition  $Z = 1$  holds is very narrow. For this reason, it has been difficult to obtain satisfactory electro-magnetic wave absorption characteristic over a wide frequency bandwidth.

Accordingly, a principal object of this invention

is to provide a novel electro-magnetic wave absorbing material and an electro-magnetic wave absorbing body utilizing the same that can increase electric loss contributing to the absorption of electro-magnetic waves, 5 can stably control the loss and can widen the field of use of such material and body.

Another object of this invention is to provide a novel electro-magnetic wave absorbing body capable of efficiently absorbing electro-magnetic waves over a wide 10 frequency range.

According to one aspect of this invention, there is provided an electro-magnetic wave absorbing material comprising a mixture of short fibers of metal or alloy having a high electric conductivity, a length of 0.1 mm 15 mm to 50 mm and a length to diameter ratio larger than 10, a ferromagnetic material and a high molecular synthetic resin.

According to another aspect of this invention, there is provided an electro-magnetic wave absorbing body 20 comprising an electro-conductive base, a low input impedance layer disposed on the base, and an impedance transforming layer disposed on the low input impedance layer, the low input impedance layer consisting of a mixture of short fibers of metal or alloy having a high 25 electric conductivity, a length of 0.1 mm to 50 mm and a length to diameter ratio larger than 10, a ferromagnetic material and a high molecular synthetic resin.

The invention will be explained in detail by means of non-limitative examples and with reference to the drawings wherein

Fig. 1 is a diagrammatic representation showing  
5 the construction of the electro-magnetic wave absorbing material of this invention;

Fig. 2 is a graph showing the relationship among the quantity of short brass fibers, a real part ( $\text{Re}(\dot{\epsilon})$ ) and an imaginary part ( $\text{Im}(\dot{\epsilon})$ ) of the complex dielectric  
10 constant;

Fig. 3 is a graph showing the relationship among the quantity of short brass fibers and frequency characteristics of the complex permeability ( $\text{Re}(\dot{\mu})$ ,  $\text{Im}(\dot{\mu})$ );

15 Fig. 4 is a partial sectional view showing a laminated electro-magnetic wave absorbing body embodying the invention;

Fig. 5 is a Smith Chart showing an input impedance characteristic measured from above a low input  
20 impedance layer formed on a metal sheet and an input impedance characteristic measured from above an impedance transforming layer laminated on the low input impedance layer;

Fig. 6 shows a reflection loss characteristic  
25 obtained by converting characteristic B shown in Fig. 5, and a reflection loss characteristic of a prior art electro-magnetic wave absorbing body;

Fig. 7 is a graph comparing the frequency bandwidths of a low input impedance layer and an impedance transforming layer manifesting a magnetic loss;

Fig. 8 and 9 show the input impedance characteristic and the reflection loss characteristic of only the low input impedance layer of the Example 1 to be described later;

Fig. 10 and 11 show the input impedance characteristic and the reflection loss characteristic of only the low input impedance layer of Example 2;

Figs. 12 and 13 show the input impedance characteristic and the reflection loss characteristic of only the low input impedance layer of Example 3; and

Figs. 14 and 15 show the input impedance characteristic of the low input impedance layer alone and the reflection loss characteristic of Example 4.

In a preferred embodiment shown in Fig. 1, into a mixture 1 of ferrite and a high molecular synthetic resin or a mixture of ferrite, a high molecular synthetic resin and carbon black are incorporated short fibers 2 of metal. Preferably each of the metal fibers 2 have a length (L) of 0.1 - 50 mm, and a length (L) to diameter (D) ratio L/D of larger than 10. The quantity of the metal fibers 2 to be incorporated should be larger than 3% by weight. The metal should have a high electric conductivity, such as Au, Ag, Cu, Al, Zn, Ni, Fe or alloys thereof. The ferrite

may be also substituted by a ferromagnetic material such as iron, cobalt and nickel.

The electric wave characteristic of the electro-magnetic wave absorbing material of this invention will be described as follows.

Fig. 2 shows complex dielectric constant [ $\dot{\epsilon} = \text{Re}(\dot{\epsilon}) - j \text{Im}(\dot{\epsilon})$ ] of a composition comprising epoxide resin, iron ferrite ( $\text{Fe}_3\text{O}_4$ ) and short fibers of brass measured at a frequency of 9.4 GHz. Each of short brass fibers have a length L of about 2 mm a diameter (D) of about 50 microns, and a ratio L/D of about 40. The graph shown in Fig. 2 shows that the incorporation of the short brass fibers increases  $\text{Re}(\dot{\epsilon})$  and  $\text{Im}(\dot{\epsilon})$  to greatly vary electric characteristics.

This reason can be qualitatively explained as follows.

When a short metal fiber is placed in a electromagnetic field, the metal fiber is polarized by the electric field component. Since the extent of polarization can be obtained by a product of the electric charge quantities separated at both ends of the short metal fiber and the length of the fiber, a thin long metal fiber is suitable for efficiently creating polarization. Where a plurality of metal short fibers is irregularly present in the electro-magnetic field, an average polarization effect of respective fibers appears. Accordingly, an electro-magnetic wave absorbing material

containing a plurality of short metal fibers can be equivalently considered as a material having a large polarization, thus making large the real part  $\text{Re}(\dot{\epsilon})$  of the complex dielectric constant representing the magnitude of  
5 the polarization.

Where a plurality of layers of the electric wave absorbing material each having a thickness substantially equal to the wavelength of the electric wave are laminated for use in a microwave frequency band, the overall  
10 thickness of the lamination is in a range of 0.1 mm to 50 mm. Preferably the length of the fibers is in a range of 0.1 to 50 mm. Since the fiber should have a thin and elongated configuration, the ratio  $L/D$  should be larger than 10.

15 While in the foregoing, the real part  $\text{Re}(\dot{\epsilon})$  of the complex dielectric constant has been described, it is considered that the imaginary part  $\text{Im}(\dot{\epsilon})$  is influenced by the variation of the electric conductivity caused by the incorporation of the short metal fibers. More  
20 particularly, incorporation of the short metal fibers increases conductive current, hence electric loss, with the result that the imaginary part  $\text{Im}(\dot{\epsilon})$  of the complex dielectric constant representing the loss increases. For this reason, for the purpose of efficiently increasing the  
25 imaginary part  $\text{Im}(\dot{\epsilon})$  of the complex dielectric constant it is necessary to use short metal fibers made of metal or alloy having a large electric conductivity.



The characteristics shown in Fig. 2 can be reproduced at a high fidelity as long as the same type of short metal fibers are used. Where metals of different type or fibers having different dimensions are used it is  
5 necessary to clarify the relationship among the quantity of the short metal fibers incorporated, the real part  $\text{Re}(\epsilon)$  and the imaginary part  $\text{Im}(\epsilon)$  of the complex dielectric constant.

The magnetic characteristic will be discussed as  
10 follows. Since the electro-magnetic wave absorbing material of this invention contains ferrite, it can manifest a magnetic loss. Fig. 3 shows the result of measurement of the complex dielectric constant (measured at a frequency of 1 GHz - 10 GHz) of the electro-magnetic  
15 wave absorbing members respectively consisting of epoxide resin, 70% by weight of iron ferrite ( $\text{Fe}_3\text{O}_4$ ) and 0%, 5% and 15% by weight of short brass fibers. Even when the quantity of incorporation of short brass fibers is varied in the range of 0 - 15% by weight, both the real part  $\text{Re}(\mu)$   
20 and the imaginary part  $\text{Im}(\mu)$  of the dielectric constant do not vary in any appreciable extent. As described above the magnetic characteristic of the material is never influenced by the incorporation of the short metal fibers and the magnetic characteristic is governed mainly  
25 by the magnetic characteristic of the ferrite.

As described above, since the electric wave absorption material according to this invention is

incorporated with short metal fibers not only the electric characteristic can be greatly and stably adjusted but a magnetic loss can be also increased.

The type of the high molecular synthetic resin is not determined by the wave characteristic to be absorbed but rather determined by such environment conditions as weather proofness, heat resistant and shock resistant properties. In this invention, it is not necessary to use any specific resin, where the electro-magnetic wave absorbing material is applied by blasting, epoxy resin is preferred. However, when the material is applied onto a curved surface flexible rubber is advantageous.

The electro-magnetic wave absorbing material can be laminated to form an electro-magnetic wave absorbing body as shown in Japanese Laid Open Patent Specification No. 10902/1982. Moreover, since it has a large loss for the electric wave, it can be used as an electro-magnetic shield member.

Some embodiments of the electric wave absorbing body using the electro-magnetic wave absorbing material characterized by the present invention will be explained as follows.

The electric wave absorbing body shown in Fig.4 comprises a low input impedance layer 13 formed on an electro-conductive sheet or plate transforming layer 14 formed on the low input impedance layer 13. The electro-conductive plate 12 constitutes a conductor

portion of the basic member to be coated with the electro-magnetic wave absorbing material. The term "low input impedance layer" means a layer having a characteristic wherein the input impedance characteristic is located near the left end of a Smith Chart as shown at A in Fig. 5. Although this layer 13 manifests a large loss for electric wave, when it is merely applied onto an electro-conductive sheet nearly all electric waves are reflected by the surface of the layer 13 thus failing to provide a satisfactory electro-magnetic wave absorbing body. According to this embodiment, for the purpose of efficiently transmit electromagnetic wave to the low input impedance layer 13, the impedance transforming layer 14 is provided as shown in Fig. 4 which operates in the same manner as a 1/4 wavelength impedance transformer utilized in microwave technology so that the layer 14 is designed in the same manner as the 1/4 wavelength impedance transformer. Let us denote by R the value of the real part at a frequency  $f_0$  at which the imaginary part becomes zero. Then the impedance transforming layer 14 acts as an impedance transformer when the surge impedance of the layer 14 is made  $Z_w = \sqrt{R}$  and when the thickness of the layer 14 is made to be 1/4 of the wavelength at the frequency  $f_0$ . Ordinary materials have dielectric constants of larger than 2 and their surge impedance is expressed by  $Z_w = \sqrt{\frac{\mu}{\epsilon}}$ . From the foregoing relation it can be understood that R must be less than 0.5. Where such

impedance transforming layer 14 is provided the input impedance characteristic as seen from its surface becomes that shown by B in Fig. 5. When this characteristic is expressed in terms of reflection loss, a characteristic as shown by C in Fig. 6 can be obtained. Curve D shown in Fig. 6 is the characteristic of the prior art electro-magnetic wave absorbing body without including short metal fibers characterized by the present invention. From the characteristics C and D shown in Fig. 6, it will be seen that by utilizing the electro-magnetic wave absorbing material according to this invention, the frequency bandwidth in which the reflection loss becomes more than 20dB is widened. In Fig. 5 numerals 8 and 13 show the characteristics at frequencies 8 GHz - 13 GHz.

The low input impedance characteristic can also be improved by further adding a ferroelectric substance for an electro-conductive substance. Typical ferroelectric substances include barium titanate, lead titanate, strontium titanate, lead neobate, and lead zirconate.

The electro-magnetic wave absorption characteristic of the electro-magnetic wave absorbing material of this invention is as follows.

In order to efficiently absorb electro-magnetic wave, it is essential to form the low impedance layer with the high molecular weight resin and material having a high electric conductivity as can be clearly understood from the foregoing description. We have found that it is

necessary to incorporate into the low impedance layer magnetic substance that impart magnetic loss to the low impedance layer in order to realize an excellent electro-magnetic wave absorption characteristic over a  
5 wide frequency bandwidth.

Curve A shown in Fig. 5 shows the input impedance characteristic where there is a magnetic loss while curve A' shows the input impedance characteristic where there is no magnetic loss. In both characteristics A and A', the  
10 value R of the real part at a frequency at which the imaginary part becomes zero is about 0.3, but at a frequency of 8 - 13 GHz, the characteristics become different so that the electro-magnetic wave absorbing characteristics where the electro-magnetic wave absorbing  
15 body is fabricated by laminating the impedance transforming layer 14 become also different. The results of calculations of the low input impedance transforming layers 13 incorporated with magnetic loss and not are shown by curves E and F in Fig. 7 which shows the relation  
20 between a value obtained by dividing a frequency bandwidth in which a reflection loss of more than 20 dB occurs with the center frequency of the bandwidth, and the input impedance R. As can be clearly noted by comparing characteristics E and F shown in Fig. 7 the characteristic  
25 F having magnetic loss has a wider frequency band characteristic. For this reason, it is desirable for the electro-magnetic wave absorbing body to incorporate

magnetic loss in the low input impedance layer 13. In Fig. 7, the relation of magnetic loss between the low impedance layer 13 and the impedance transforming layer 14 is as follows:

Curve	Magnetic loss of the low impedance layer 13	Magnetic loss of the impedance transforming layer 14
E	without	without
F	with	without
G	with	with

Considering the impedance transforming layer 14, when the input impedance value of the low input impedance layer 13 is expressed by R its surge impedance must be  $Z_w = \sqrt{R}$ . Consequently, depending upon the value of R even a  
5 high molecular resin itself may be used or for the purpose of fulfilling the conditions described above magnetic substance in the form of particles, foils or short fibers is incorporated into the high molecular synthetic resin. By combining the high molecular synthetic resin and the  
10 magnetic material an electro-magnetic wave absorbing body having desired impedance conversion capability and electric loss can be provided. As a result of various calculations, we have found that impartion of magnetic loss is effective to widen the frequency band.  
15 Characteristics F and G shown in Fig. 7 show this fact, in which characteristic G has a wider frequency bandwidth. Accordingly, in the electro-magnetic wave absorbing body of this invention it is desirable to impart magnetic loss to the impedance transforming layer 14. Magnetic loss can  
20 be imparted by incorporating the same material that imparts magnetic loss to the low input impedance.

Thermoplastic resins and thermosetting resins can be used as the high molecular synthetic resins utilized to form low input impedance layer 13 and the impedance  
25 transforming layer 14 and even when either one of these resins are used the same electric wave characteristic can be obtained. A flexible electro-magnetic wave absorbing

body is easy to handle. To this end, natural or synthetic rubber can be used.

To have better understanding of this invention the following examples are given.

5 Example 1

Polyethylene, ferrite and short brass fibers were mixed together at a weight ratio of 30:70:24, and a sheet of this mixture having a thickness of 1.0 mm was used as a low input impedance layer 13. A sheet having a thickness  
10 of 3.6 mm and containing polyethylene and ferrite at a weight ratio of 60:40 was used as an impedance transforming layer 14 to obtain an electro-magnetic wave absorbing body. Fig. 8 shows the input impedance characteristic of the low input impedance layer 13 alone,  
15 while Fig. 9 shows the reflection loss characteristic.

Example 2

A polybutadiene resin, ferrite, and iron short fibers were admixed at a weight ratio of 30:70:15 and a sheet of this mixture having a thickness of 0.9 mm was  
20 used as the low input impedance layer 13. A sheet having a thickness of 3.8 mm and consisting of a mixture of polybutadiene resin, and ferrite at a ratio of 70:30 was used as the low impedance transforming layer 14 to form an electro-magnetic wave absorbing body. Fig. 10 shows the  
25 input impedance characteristic of the low input impedance layer 13 alone, while Fig. 11 shows the reflection loss characteristic.



Example 3

A polybutadiene resin and short iron fibers were mixed together at a weight ratio of 75:25 and the mixture was shaped into a sheet having a thickness of 1.4 mm.

5 This sheet was used as a low input impedance layer 13 and a sheet of butadiene resin having a thickness of 4.6 mm was used as an impedance transforming layer 14 to form a electro-magnetic wave absorbing body. Fig. 12 shows the input impedance characteristic of the low input impedance  
10 layer 13 alone, while Fig. 13 shows the reflection loss characteristic.

Example 4

Chloroprene rubber, ferrite, carbon and short brass fibers were admixed at a weight ratio of 30:70:5:10  
15 and the mixture was formed into a sheet having a thickness of 1.0 mm. This sheet was used as a low input impedance layer 13. A sheet having a thickness of about 3.6 mm and consisting of a mixture of chloroprene rubber, ferrite and carbon at a ratio of 70:30:5 was used as an impedance  
20 transforming layer 14 to obtain an electro-magnetic wave absorbing body. Fig. 14 shows the input impedance characteristic of the low input impedance layer 13 alone, and Fig. 15 shows a reflection loss characteristic.

As many apparently widely different embodiment of  
25 this invention may be made without departing from the spirit and scope thereof, it is to be understood that then invention is not limited to the specific embodiments thereof except as defined in the appended claims.

- 1 -

C l a i m s

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5 1. An electro-magnetic wave absorbing material  
characterized by a mixture of short fibers (2) of metal  
or alloy having a high electric conductivity, a length  
of 0.1 mm to 50 mm and a length to diameter ratio larger  
than 10, a ferromagnetic material and a high molecular  
10 synthetic resin.

2. The electro-magnetic wave absorbing material  
according to claim 1 wherein said material contains  
15 more than 3 % by weight of the short fibers (2).

3. The electro-magnetic wave absorbing material  
according to claim 1 or 2, wherein the metal or alloy  
20 is selected from the group consisting of Au, Ag, Cu, Al,  
Zn, Ni, Fe and alloys thereof.

25 4. The electro-magnetic wave absorbing material  
according to any of claims 1 to 3, wherein the ferro-  
magnetic material is selected from the group consisting  
of ferrite, iron, cobalt and nickel.

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5. The electro-magnetic wave absorbing material  
according to any of claims 1 to 4 which further com-  
prises carbon black.

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1        6.        The electro-magnetic wave absorbing material  
         according to any of claims 1 to 5, which further  
         comprises a ferroelectric substance.

5  
         7.        The electro-magnetic wave absorbing material  
         according to claim 6, wherein the ferroelectric  
         substance is selected from the group consisting of  
10        barium titanate, lead titanate, strontium titanate,  
         lead neobate and lead zirconate.

15        8.        An electro-magnetic wave absorbing body  
         characterized by a low input impedance layer (13) formed  
         on a electro-conductive member (12), and an impedance  
         transforming layer (14) formed on the low input impe-  
20        dance layer (13), the low input impedance layer (13)  
         comprising a mixture of short fibers (2) of metal or  
         alloy having a high electric conductivity, a length  
         of 0.1 mm to 50 mm                      and a length to diameter  
25        ratio larger than 10, a ferromagnetic material and a  
         high molecular synthetic resin..

30        9.        The electro-magnetic wave absorbing body  
         according to claim 8 wherein the impedance transforming  
         layer (13) is made of a high molecular synthetic resin.

35        10.       The electro-magnetic wave absorbing body  
         according to claim 8 or 9 wherein the impedance trans-  
         forming layer comprises a mixture of a high molecular

1     synthetic resin and either one or both of a magnetic  
material and an electro-conductive material each in  
the form of particles, foils and short fibers.

5

11.     The electro-magnetic wave absorbing member  
according to claim 10 wherein the magnetic material  
comprises a ferromagnetic material selected from the  
10     group consisting of ferrite, iron, cobalt, nickel and  
mixtures thereof.

12.     The electro-magnetic wave absorbing body  
15     according to claim 10 or 11 wherein the electro-  
conductive material comprises at least one of electro-  
conductive metals, alloys of metals and carbon.

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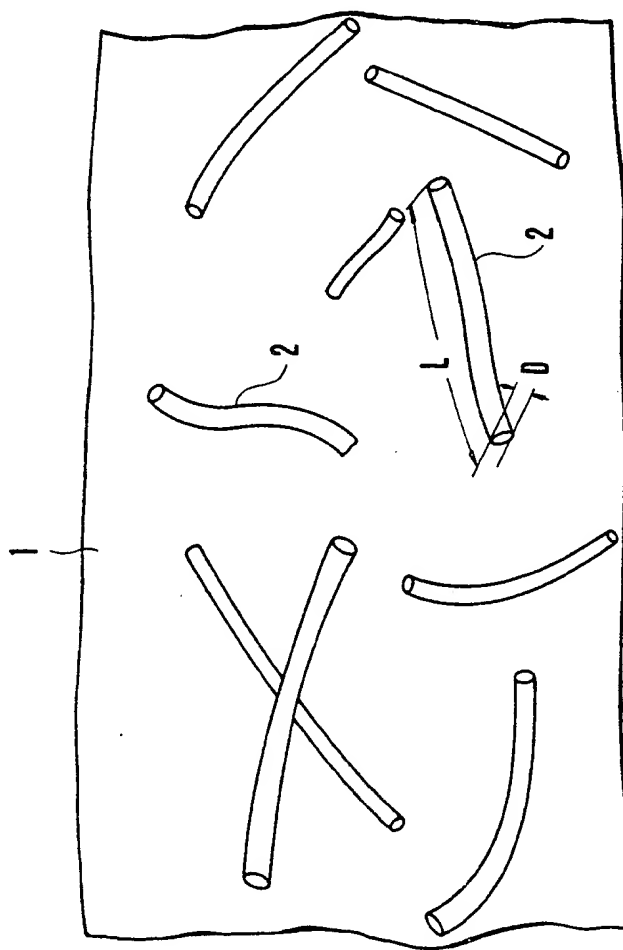


FIG. 1

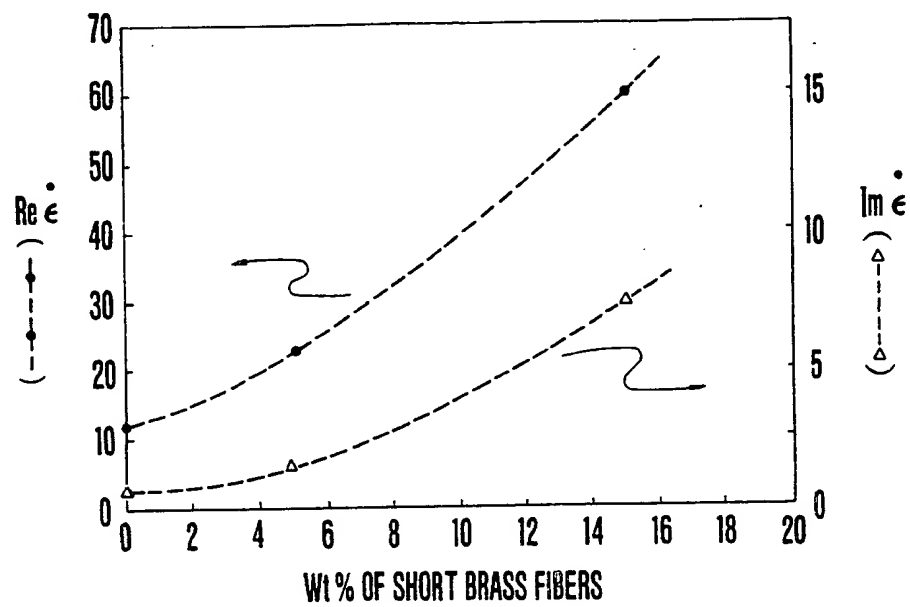


FIG.2

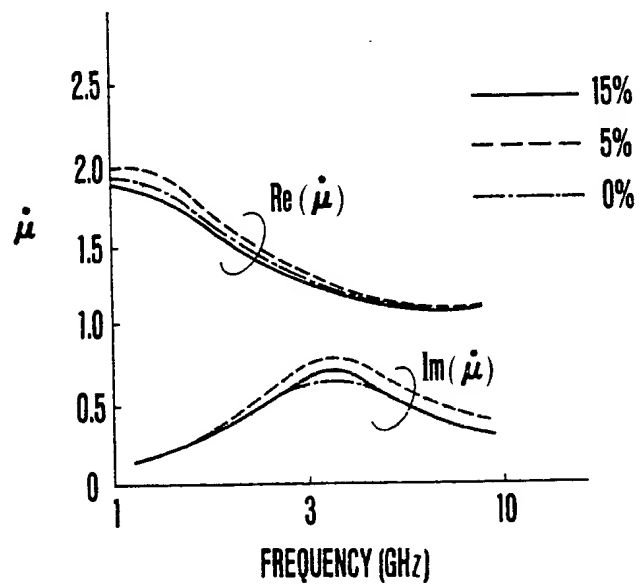


FIG.3

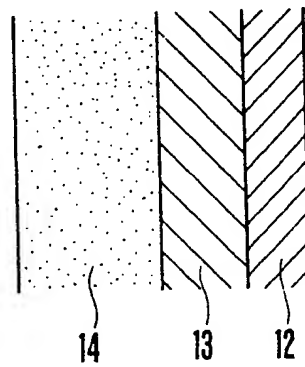


FIG. 4

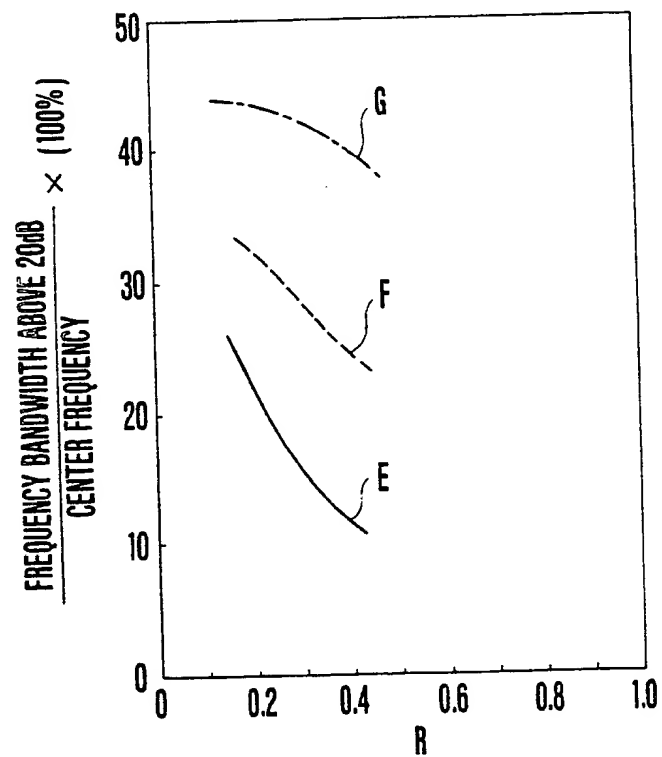


FIG. 7

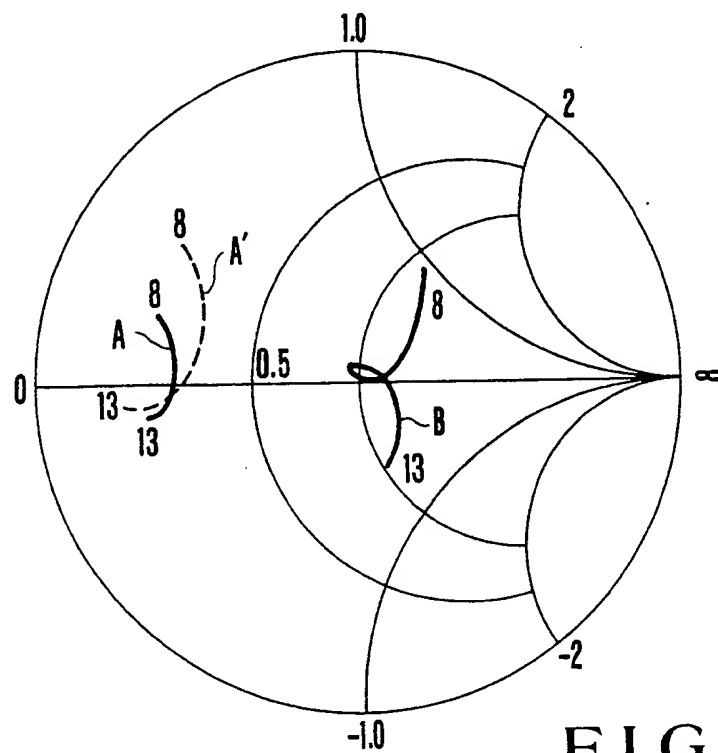


FIG.5

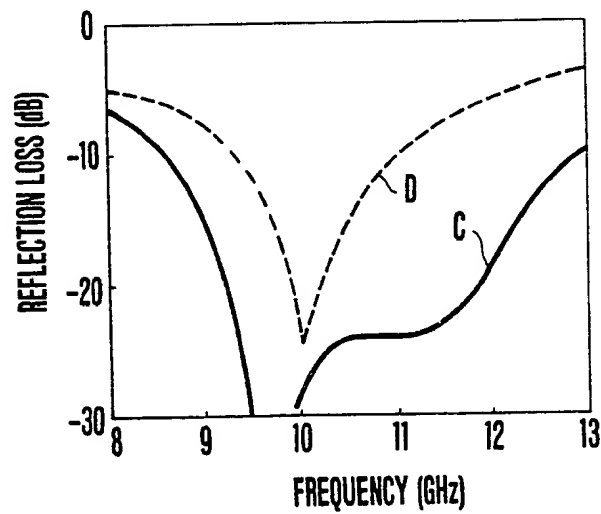


FIG.6



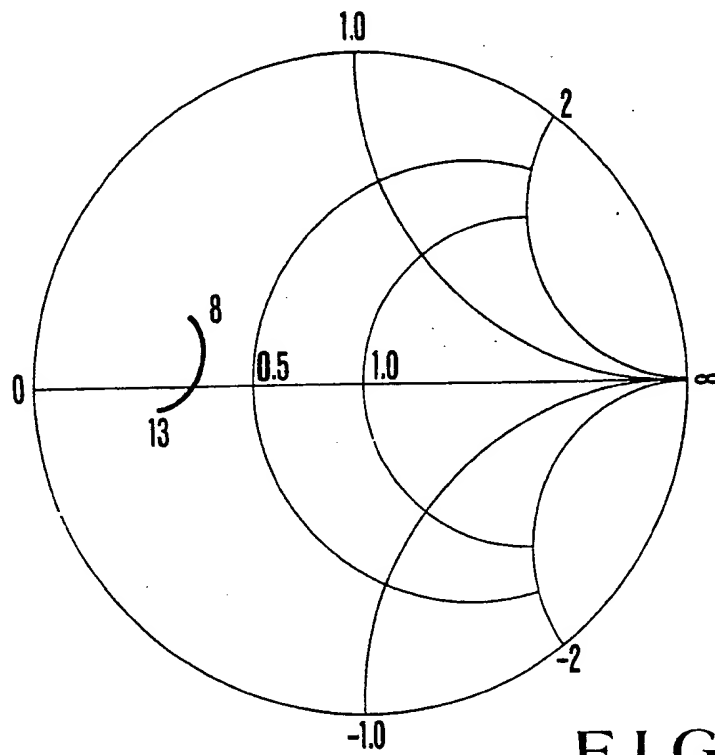


FIG.8

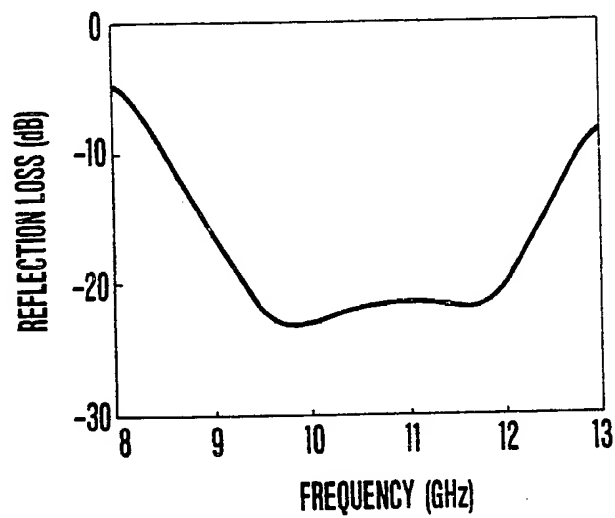


FIG.9

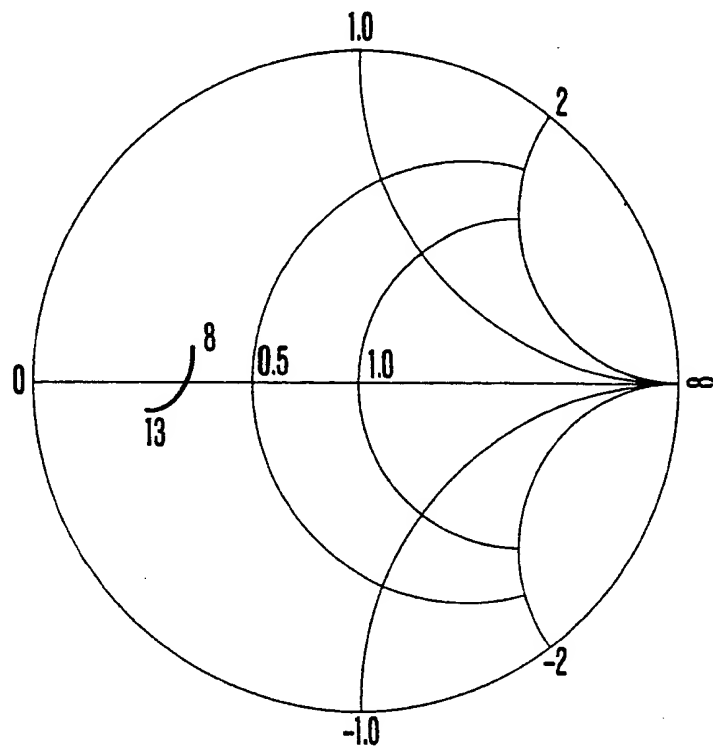


FIG.10

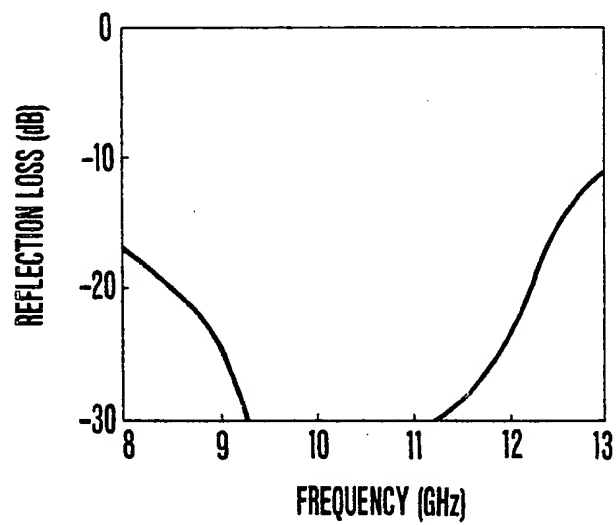


FIG.11

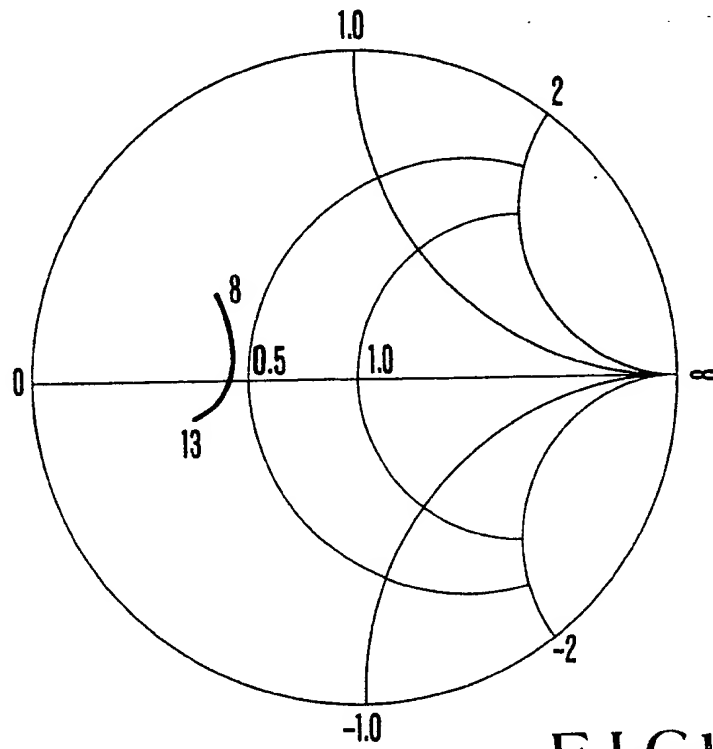


FIG.12

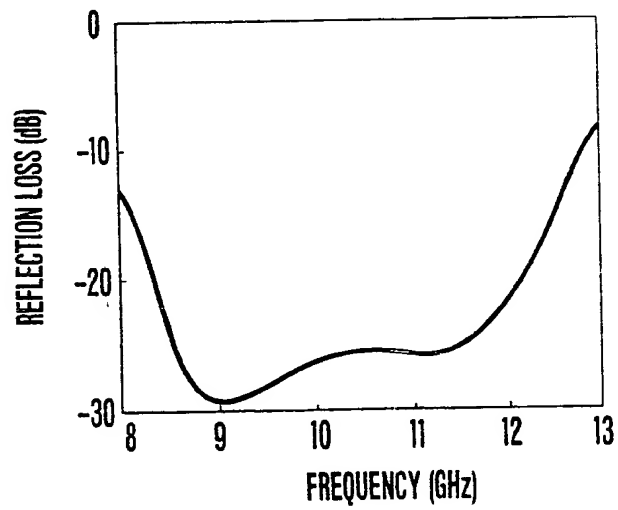


FIG.13

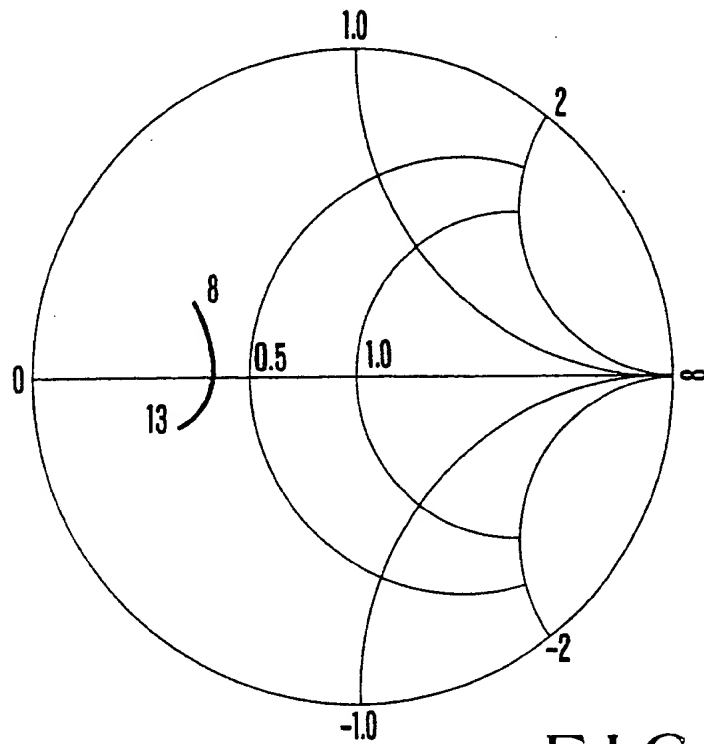


FIG.14

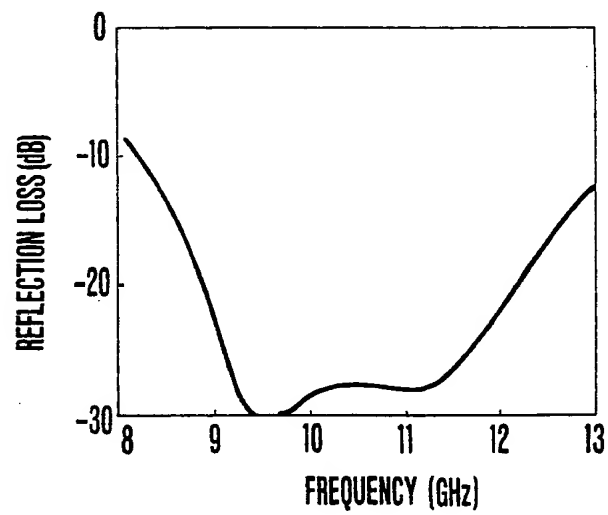


FIG.15